Enhancing the Chemical Properties and Recovery Rates of Organic Fertilizer through Carbon-to-Nitrogen (C/N) Ratio Manipulations of Biomass Wastes

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Enhancing the Chemical Properties and Recovery Rates of Organic Fertilizer through Carbon-to-Nitrogen (C/N) Ratio Manipulations of Biomass Wastes

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Abstract: *This research explored the impact of varying carbon-to-nitrogen (C/N) ratios in different organic biomass wastes on compost recovery and chemical properties. Using a split-plot design within a completely randomized setup, the study investigated the outcomes of compost derived from combining poultry manure (PM) with rice straw (RS) and carbonized rice hull (CRH) at different C/N ratios, ranging from 15:1 to 35:1. Chemical analyses revealed distinct characteristics for each biomass waste. CRH exhibited the highest organic carbon (OC) content, followed by RS and PM. PM showed the highest total nitrogen (N) and total phosphorus (P), while CRH had the highest total potassium (K) due to the ash component from its heat treatment. Additionally, PM exhibited the highest total nitrogen-phosphorus-potassium (NPK) content, followed by CRH and RS. CRH displayed the highest C/N ratio, followed by RS and PM. Over a two-month composting period for the PMRS and PMCRH biomass mixtures, it was observed that increasing C/N ratios enhanced compost recovery but decreased pH, OC, total P, total K, total NPK, and the final C/N ratios of PMRS. Similarly, increasing C/N ratios lowered the pH, total P, total K, and total NPK of PMCRH. Despite these variations, both biomass mixtures consistently produced composts with notably high levels of nitrogen, phosphorus, potassium, and overall NPK.*

Keywords: C/N ratio, biomass wastes, carbonized rice hull, compost recovery, organic fertilizer.

1. INTRODUCTION

Biomass wastes, also known as agrowastes, include crop residues left after harvest and serve as a significant source of organic matter when decomposed in the soil. This natural process is essential for converting organic materials into forms that plants can readily absorb for nutrition. However, the increasing volume of agricultural waste, driven by advancements in production strategies, exceeds the natural decomposition rates. Therefore, transforming these low-value, high-volume wastes and by-products into high-value materials or energy has become increasingly important [25-26].

The management of excessive agricultural waste poses a critical concern due to its potential negative environmental repercussions when mishandled. A key challenge in addressing agricultural waste lies in its elevated Carbon-to-Nitrogen (C/N) ratios, which significantly prolong the decomposition process. This extended decomposition period makes the waste less immediately suitable as a fertilizer for soil. As a result, the accumulation of biomass outpaces its decomposition rate, leading to complications when proper containment and management practices are not employed. This imbalance can have far-reaching consequences, highlighting the urgency of implementing effective strategies to mitigate the environmental impact of agricultural waste mismanagement.

In the Philippines, poultry manures from broiler and layer chickens are prevalent, according to the Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development [1]. Additionally, a substantial quantity of rice straw—ranging from 18 to 27 tons per year—is not collected for composting and nutrient recycling. Instead, some are repurposed as feed, burnt, or simply left in the fields [2]. Furthermore, an estimated 2 tons of rice hulls are generated annually. Transforming these rice hulls into carbonized rice hulls (CRH) enhances their suitability as a component in compost [1]. This process adds value to the waste stream, contributing to more effective and sustainable waste management practices.

Numerous research efforts have been undertaken to formulate effective management strategies for harnessing the potential of organic raw materials. However, unraveling the intricacies of decomposition patterns necessitates a comprehensive understanding of the interplay among various constituent elements. Presently, diverse composting technologies strive to transform raw materials into organic matter suitable for efficient agricultural use. Nevertheless, a recurring challenge emerges when dealing with higher Carbon-to-Nitrogen (C/N) ratios in biomass, limiting the production of organic fertilizers. Achieving a harmonious balance between carbon and nitrogen is essential for expediting the decomposition process, underlining the importance of precision in managing these elemental ratios for optimal outcomes in organic fertilizer production.

Worldwide, food production has been pressured by increasing land degradation, high input costs, climate change, etc. [2]. Sustainable production using organic fertilizers can address the increasing fertilizer prices and amend the degraded soils. Organic materials have numerous beneficial effects when added to the soil. They increase soil fertility, provide a balanced supply of nutrients, and build up organic matter (OM). However, these beneficial effects are dependent on the nature of organic materials, their nutrient content, and the process of their decomposition in the soil [1]. Research shows that the application of OM improves the rhizosphere ecosystem, suppresses soil-borne pathogens, and promotes plant growth [3]. Furthermore, organic materials such as compost have a considerable effect on the soil's physical properties, such as structure, bulk density, porosity, and others [1]. Also, composting is an excellent approach to attaining improved and sustainable agricultural productivity. Enhanced crop productivity is due to the retrieval of nutrients from plant biomass and animal manure through composting [2]. Organic matter content serves as an indicator of soil fertility. It has a profound impact on the overall health and productivity of the soil. This element significantly enhances the ability of the soil to retain nutrients, leading to an increased availability of crucial elements such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and various other essential nutrients [1]. These nutrients are vital for sustaining the metabolic processes of plants and maintaining their overall well-being.

In sustainable cropping systems, OM plays a multifaceted role in bolstering the physical, chemical, and biological properties of the soil [4]. Notably, it fosters the granulation of soil particles, forming stable aggregates with well-balanced micro and macropores. This granulation, in turn, enhances the soil's aeration and porosity, creating an environment conducive to optimal plant growth [5]. Furthermore, the significance of organic matter extends to its role in stimulating the activity of soil organisms. By serving as a valuable energy and carbon source, organic matter creates an environment that supports the proliferation of beneficial soil microorganisms. This, in turn, contributes to the suppression of plant pathogens through the production of antibiotics [6]. In essence, organic matter acts as a catalyst for a thriving soil ecosystem, fostering a dynamic interplay between soil components that ultimately benefits plant health and crop yields.

Aligned with the provisions of Republic Act 10068, the Department of Agriculture, entrusted with advancing agricultural development in the Philippines, actively advocates for the widespread adoption of organic farming practices among food growers. This strategic initiative serves a dual purpose: ensuring food safety and promoting environmental protection. As the momentum for organic farming gains traction, there is a growing demand for organic matter sources to meet the evolving needs of sustainable agriculture.

In this connection, there arises a crucial necessity to optimize the production of organic fertilizer, especially in the context of supporting community-based food production programs. Investigating the proper balance of carbon (C) and nitrogen (N) in feedstocks becomes imperative for expediting decomposition processes and facilitating the rapid production of organic matter through composting. This research initiative is essential in aligning agricultural practices with the principles of organic farming and enhancing the efficiency of organic fertilizer production to meet the demand of the evolving food production landscape.

In response to the escalating demand for organic fertilizer, this study was designed with the primary objective of refining organic fertilizer production processes. The focus revolved around experimenting with different carbon-to-nitrogen (C/N) ratios across various organic biomass wastes to enhance decomposition rates and subsequently evaluating the quality of the resulting compost. Specifically, this study sought to:1) analyze the chemical properties of rice straw, carbonized rice hull, and poultry manure; 2) determine the recovery rates and chemical properties of composts produced from the decomposition of biomass wastes with different C/N ratios.

2. MATERIALS AND METHODS

2.1 Collection of Biomass Wastes

The materials utilized in this study, namely poultry manure, rice straw, and rice hull, were sourced from the Silliman University College of Agriculture Scheide Farm. Subsequent to collection, rice hulls underwent a carbonization process. To enhance the efficiency of decomposition, the rice straw was meticulously shredded and homogenized into smaller sizes, approximately 3-5 cm, to increase the surface area accessible for microbial activity.

A daily collection routine for poultry manure was implemented, mitigating the risk of flies laying eggs in accumulated manure piles on the farm. The freshly collected manure was promptly transferred to the designated mixing area for organic fertilizer production, ensuring a controlled and conducive environment for the subsequent processes.

2.2 Feedstock and Compost Chemical Properties.

The biomass wastes and resulting compost chemical properties such as pH, OC, total N, total P, and total K were analyzed to determine the present essential elements. The pH (compost-water mixture ratio of 1:5 w/v) was analyzed using a glass electrode pH meter [7]. The OC was analyzed using the Walkley and Black method [8] [9], total N by the Kjeldahl method [10], total P by the Vanadomolydate method [11], and total K by a flame photometer [12]. The chemical analyses were conducted at the Analytical Service Laboratory, Agricultural Systems Institute, College of Agriculture and Food Science, UPLB, College, Laguna, Philippines

2.3. Moisture Content Determination

Twenty grams of each feedstock was placed in oven-dried and pre-weighed 50 mL-beakers and dried in the oven for 24 hours at 110˚C. Dry basis moisture content (Md) was measured using Equation 1.

$$M_d = \frac{M_w}{W_d} \text{ x } 100 \qquad \text{Equation 1.}$$

Wherein M_d was the moisture content on a dry basis, W_w was the weight of water in the material which is just a difference between Wet weight and the dry matter, and W_d was the weight of the dry matter.

2.4. Container for Feedstock Mixture Preparation

Plastic pails (10kg capacity) were used to contain biomass waste mixtures with varying levels of C/N. The small holes at the bottom of each pail drained excess water from the system, maintaining the field moisture.

2.5. *Different Feedstock Carbon-Nitrogen (C/N) Preparation*

The preparation of different C/N ratios of PM mixed with RS and PM mixed with CRH was based on the moisture content, organic carbon, and total nitrogen analyses. To attain the 15, 20, 25, 30, and 35 C/N ratios of the feedstock mixture of two materials to be mixed, determination of organic carbon, total nitrogen through chemical analysis, and moisture contents through oven drying were conducted. The organic C, total N, and moisture content data were plugged in the formula (Equation 2) adopted from Cornell Waste Management Institute, Cornell University [13].

$$R = \frac{Q1(C1 * (100 - M1) + Q2(C2 * (100 - M2)}{Q1(N1 * (100 - M1 + Q2(N2 * (100 - M2)}$$

Equation 2

Wherein R was the C/N ratio, Q_n was the mass of material n ("as is", or "wet weight"), Cn was the carbon (%), N_n was the nitrogen (%), and M_n was moisture content (%) of material n.

Alternately, the derived formula in Equation 3 was used to determine the volume of another material (kg) to be mixed to attain the desired C/N.

$$Q2 = \frac{Q1 \text{ x } N1 \text{ x } \left(R - \frac{C1}{N1}\right) \text{ x } (100 - M1)}{N2 \text{ x } \left(\frac{C2}{N2} - R\right) \text{ x } (100 - M2)}$$

Equation 3

Wherein R was the C/N ratio, Q_n was mass of material n ("as is", or "wet weight"), Cn was the carbon (%), N_n was the nitrogen (%), and M_n was the moisture content (%) of material n.

On the other hand, moisture content was a critical variable in the mixture. The moisture content of the feedstock mixtures was maintained at 50-60% for one month during the decomposition period and allowed to air-dry for one month for the aging process. Mixing of the pile was done daily to enable uniform distribution of moisture and aeration. There was a daily observation and monitoring to assess the physical degradation of each experimental unit and avoid frogs, lizards, etc., from getting inside the pail that might alter the physical, biological, and chemical decomposition of the feedstocks.

2.6. Feedstock Pile Temperature

Every day at 9:00 AM, the temperature was determined in each experimental unit during the decomposition period. In organic material decomposition, the energy released, which is not used by microorganisms, is liberated as heat. High temperature is suitable for speeding up decomposition and killing pathogens, but too much-prolonged heat retards decomposition. The temperature was measured using a TEL-RU thermometer. Dry basis moisture was used for describing moisture changes during the drying of compost. When a sample loses or gains moisture, the difference in the dry basis moisture is linearly related to the weight loss or gain. The moisture data of each feedstock were plugged in the formula to attain the desired C/N ratios for each treatment.

2.7. Compost Recovery

The weight of the substrate was recorded at the start, while compost and partially composted substrate was noted at the end of the experiment. The samples were taken from all the treatments for moisture analysis on a dry basis for weight correction factor. The percentage compost yield on a dry basis was computed using Equation 4.

$$\text{Yield (\%)} = [M_c/M_{raw}] \text{ x } 100 \qquad \text{Equation 4}$$

wherein M_c is the mass of compost (kg), and M_{raw} is the mass of raw feedstock biomass (kg).

2.8. Experimental Design

The experiment was designed as a split-plot within a completely randomized design (CRD). Five treatments were applied, each with three replications for the two feedstock mixtures, PMRS and PMCRH. During the preparation of the different feedstock mixtures with various C/N ratios, data on moisture, organic carbon (OC), and total nitrogen (N) were utilized. Each feedstock mixture from PMRS and PMCRH, with different C/N ratios, weighed 5 kg (see Table 1).

Table 1. Feedstock mixtures with specific volumes (kg) and C/N ratios as treatments.

Biomass Mixture		Treatments				
		T1	T2	T3	T4	T5
	C/N Ratios	**15:1**	**20:1**	**25:1**	**30:1**	**35:1**
PM+ RS	Poultry manure (kg)	4.51	4.12	3.67	3.17	2.59
	Rice straw (kg)	0.49	0.88	1.33	1.83	2.41
	Total weight (kg)	5	5	5	5	5
PM + CRH	Poultry manure (kg)	4.62	4.33	3.99	3.62	3.2
	Carbonized rice hull (kg)	0.38	0.67	1.01	1.38	1.8
	Total weight (kg)	5	5	5	5	5

3.9 Data and Statistical Analysis

The data gathered in this study that was laid out in split-plot in a completely randomized design were analyzed using a two-way analysis of variance and least significant difference (LSD) through the Statistical Tool for Agricultural Research (STAR) 2.0.1 of IRRI to determine the differences between treatment means at a 5% level of significance by LSD.

A scatterplot based on a correlation matrix was also generated from STAR to observe the linear association between C/N ratio, compost recovery, and chemical properties.

3. RESULTS

4.1. Temperature

The different carbon-to-nitrogen (C/N) ratios observed in the two types of biomass mixtures consistently exhibited elevated temperature readings during the initial stages of the decomposition period. Notably, the PMRS mixture with a C/N ratio of 35:1 registered the highest temperature on Day 1, contrasting with the PMCRH mixture featuring a C/N ratio of 15:1, which recorded the lowest temperature. Over the course of the first week, there was a gradual decline in the heat release from the biomass mixtures. The temperature variations observed during this period hinted at the dynamic nature of the decomposition process. Beyond the initial week, the temperature exhibited minimal fluctuations until it eventually stabilized, persisting in a relatively constant state from Day 7 through Day 31. This stabilization suggests a significant phase in the decomposition process, marking the establishment of a more balanced and sustained state in the organic material (Fig. 1).

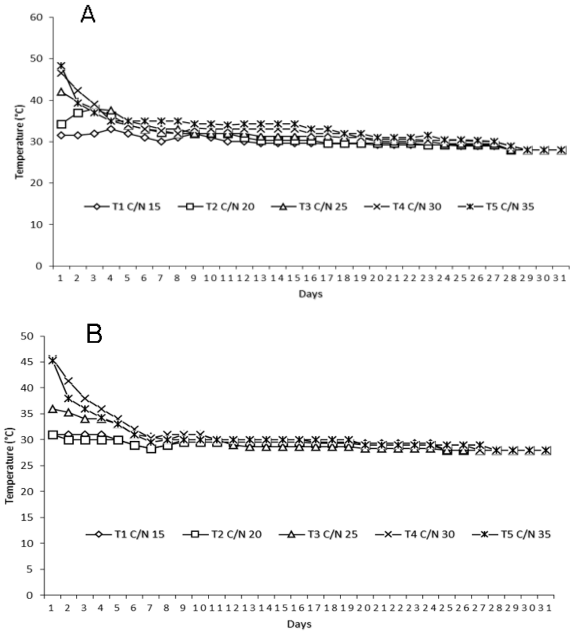

Fig. 1. Daily temperature readings within 31 days for (A) PMRS and (B) PMCRH.

3.2. Chemical Composition

The analysis of the chemical properties of the feedstocks revealed that carbonized rice hulls (CRH) exhibited the highest OC content, surpassing RS and PM. Poultry manure, on the other hand, had the highest concentrations of total N and P at 0.83% and 1.08%, respectively. While, CRH had the highest total K, attributed to the ash component generated during the heat treatment in the carbonization process. In the overall nutrient content, PM emerged as the highest in total N, P, K levels, registering at 2.06%. In comparison, CRH and RS followed with concentrations of 1.09% and 0.90%, respectively. However, when considering the C/N ratios, CRH exhibited the highest ratio, trailed by rice straw and poultry manure. Shifting focus to moisture content, poultry manure exhibited the highest moisture levels, succeeded by CRH and rice straw. This comprehensive examination sheds light on the distinctive chemical profiles of each feedstock, underscoring their varied contributions to the overall nutrient composition and moisture content in the organic material (Table 2).

Table 2. Feedstock Chemical Composition.

Feedstock	Moisture (%)	Chemical Properties (%)					
		OC	Total N	Total P	Total K	Total NPK	C/N
Rice Straw	7.69	33.22	0.65	0.11	0.14	0.90	51.11
CRH	13.06	44.28	0.74	0.16	0.19	1.09	59.84
Poultry manure	60.00	6.64	0.83	1.08	0.15	2.06	8.00

The chemical compost of composts derived from PMRS and PMCRH mixtures, encompassing pH, organic carbon (OC), total phosphorus (P), total potassium (K), and total nitrogen-phosphorus-potassium (NPK), exhibited notable differences. While no significant differences were observed in total N for PMCRH, it consistently demonstrated higher total N levels compared to PMRS. Remarkably, PMCRH, characterized by the lowest C/N ratio of 15:1, exhibited the highest pH, with values decreasing as the C/N ratios increased. This pH trend was mirrored in the PMRS compost. Conversely, the lowest pH was recorded in PMCRH (pH 6.31) under the treatment with the highest C/N ratio (35:1). Examining organic carbon concentrations, all treatments from both biomass mixtures showcased remarkably high OC levels. Specifically, PMCRH with the lowest C/N (15:1) displayed the highest OC concentration at 12.41, while PMRS with the highest C/N exhibited the lowest OC concentration at 4.57. A decreasing trend in OC values was evident in PMRS with increasing C/N ratios. However, there was no distinct trend observed in OC concentrations for PMCRH. These findings suggest the impact of varying C/N ratios on the chemical properties of composts, revealing a complex interplay between the composition of feedstock mixtures and the resultant characteristics of the produced compost (Table 3).

The total N values for the PMRS composts exhibited considerable variation, with the treatment of 30:1 C/N ratio displaying the highest total N, closely followed by the 15:1 C/N treatment. Conversely, in the PMCRH the treatment with a 30:1 C/N ratio yielded the highest N levels, followed by the 35:1 C/N treatment, although the differences were not statistically significant. While no clear trend emerged in total N values for both feedstock mixtures, PMCRH consistently demonstrated substantially higher total N levels compared to PMRS (Table 3). Total phosphorus (P) concentrations in both PMRS and PMCRH were notably high, and the values differed significantly between the two biomass mixtures. PMCRH, specifically with a 15:1 C/N ratio, exhibited the highest total P levels. A decreasing trend in total P concentrations with increasing C/N ratios was observed in both biomass mixtures. However, PMCRH consistently showed significantly higher total P levels compared to PMRS. Likewise, total K concentrations were remarkably high in both PMRS and PMCRH, demonstrating a highly significant difference between the two biomass mixtures. PMCRH, particularly with a 15:1 C/N ratio, showcased the highest total K concentration at 5.16, while PMRS with a 35:1 C/N ratio exhibited the lowest total K. A decreasing trend in total K concentrations with increasing C/N ratios was evident in both feedstock mixtures, but PMCRH consistently maintained significantly higher levels compared to PMRS (Table 3).

The total N, P, and K from PMRS and PMCRH were significantly different. A decreasing trend as the C/N increased was observed from both biomass mixtures. However, the PMCRH was significantly higher than PMRS. Specifically, PMCRH with the lowest C/N (15:1) showed the highest total N, P, K, which would be beneficial for soil health and crop production. It was worth noting that all composts produced from PMCRH had total N, P, K ranging from 5.65 to10.33 which the Philippine National Standard considered as organic fertilizers. On the other hand, PMRS had a total N, P, K ranging from 3.28 to 7.20, with treatments having C/N ratios of 15:1, 20:1, and 25:1 that produced at least 5% total NPK. Generally, the final C/N ratios of all treatments were lower than 15:1, ranging from 4:1 to 10:1. The lower C/N ratio indicates that microorganisms use C for growth and energy during decomposition

Table 3. Chemical composition of composts produced from biomass mixtures with different C/N Ratios

Feedstock Mixture	Treatment C/N	Chemical Properties						
		pH	OC (%)	Total N (%)	Total P (%)	Total K (%)	TOTAL NPK	Final C/N
PM+ RS	15	8.96^{a}	7.61^{a}	1.02^{a}	3.13^{a}	3.05^{a}	7.20^{a}	8:1^{a}
	20	8.03^{b}	6.73^{b}	0.88^{b}	2.62^{b}	2.74^{b}	6.24^{b}	8:1^{a}
	25	7.31^{cd}	4.38^{c}	0.82^{b}	1.94^{c}	2.21^{c}	4.97^{c}	5:1^{bc}
	30	7.46^{c}	4.48^{c}	1.05^{a}	1.63^{d}	1.46^{d}	4.14^{d}	4:1^{c}
	35	7.11^{d}	4.57^{c}	0.84^{b}	1.34^{e}	1.10^{e}	3.28^{e}	5:1^{b}
PM + CRH	15	9.24^{a}	12.41^{a}	1.19^{a}	3.98^{a}	5.16^{a}	10.33^{a}	10:1^{a}
	20	9.14^{b}	10.02^{c}	1.23^{a}	3.15^{b}	3.95^{b}	8.33^{b}	8:1^{bc}
	25	7.11^{c}	9.30^{d}	1.20^{a}	2.28^{c}	3.16^{c}	6.6^{c}	8:1^{bc}
	30	6.80^{d}	9.87^{c}	1.34^{a}	1.85^{d}	2.59^{d}	5.78^{d}	7:1^{c}
	35	6.31^{e}	11.81^{b}	1.31^{a}	1.79^{d}	2.55^{d}	5.65^{d}	9:1^{ab}

Note: Means with different letters (a, b, c, d, e) are statistically significant.

3.3. Compost Recovery

The recovery of composts was highly significantly different for PMRS and PMCRH. The PMCRH at 35:1 C/N had the highest % recovery, while the PMRS at 15:1 C/N had the lowest % recovery. The highest C/N (35:1) treatment from each feedstock mixture recovered most composts, and the trend declined as the C/N decreased in PMRS and PMCRH (Table 4). In the PMRS biomass mixtures, treatment means with the higher C/N such as C/N (30:1) and C/N (35:1) were not significantly different, unlike the PMCRH, which were substantially different. It was observed that PMCRH at C/N (35:1) recovered 46% of the total biomass, while PMRS at C/N (35:1) has 37%, which was far lower compared to that of PMCRH (Table 4).

Table 4. Recovery (kg) of compost from feedstock mixtures with different C/N ratios

Feedstock Mixture	Treatment C:N	Compost Recovery (kg)	Percent Recovery (%)
PM+ RS	15	0.84^{d}	17^{d}
	20	1.12^{c}	22^{c}
	25	1.56^{b}	31^{b}
	30	1.85^{a}	37^{a}
	35	1.86^{a}	37^{a}
PM + CRH	15	1.25^{c}	25^{c}
	20	1.31^{c}	26^{c}
	25	1.49^{c}	30^{c}
	30	2.02^{b}	40^{b}
	35	2.29^{a}	46^{a}

Note: Means with different letters (a, b, c, d) are statistically significant.

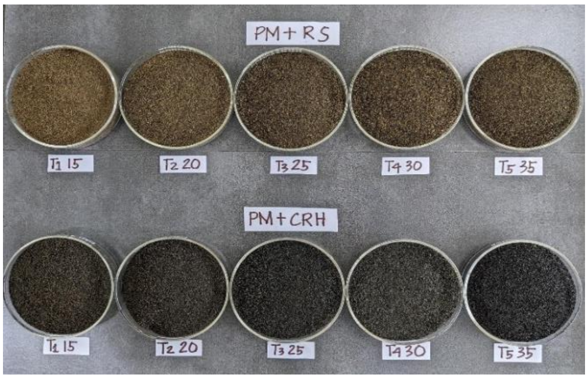

Fig. 2. Compost produced from the PM + RS and PM + CRH feedstock mixtures with different C/N ratios (15 C/N; 20 C/N; 25 C/N; 30 C/N; 35 C/N).

The composts produced from both biomass mixtures with different C/N ratios were fine, soft, and homogenous. The PMRS mixtures had brown to dark brown composts, while the PMCRH mixtures produced generally dark compost. The dark color was due to the high % OC content of compost from PM + CRH. The raw feedstocks were no longer distinguishable in the final product, indicating that the compost had undergone substantial decomposition (Figure 2).

3.4. C/N Ratio, Compost Recovery, and Chemical Property Relationships

In this study, the percent (%) recovery of compost from both PMRS and PMCRH had a very strong positive correlation with the C/N ratio. Indeed, the C/N ratio directly affected the decomposition and recovery rates of composts from raw mixtures of organic biomass wastes with different C/N ratios (15:1-35:1) (Figure 3).

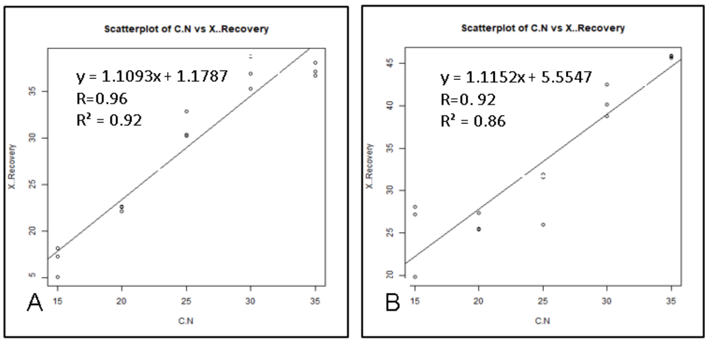

Fig. 3. Scatter plot (correlation) matrix of C/N vs. percent (%) compost recovery of (A) PMRS and (B) PMCRH.

The different levels of the C/N ratio of the feedstock mixtures influenced the chemical properties of the product. The C/N ratio in PMRS had a weak inverse correlation with the total N, a strong inverse correlation with pH and OC, and a very strong inverse correlation with total P, total K, and total NPK (Figure 4). Moreover, the C/N ratio in PMCRH had a weak positive correlation with the total N. Contrariwise, compared to PMRS, it had a weak inverse correlation with OC. However, it had a very strong inverse correlation with pH, total P, total K, and total NPK (Figure 5).

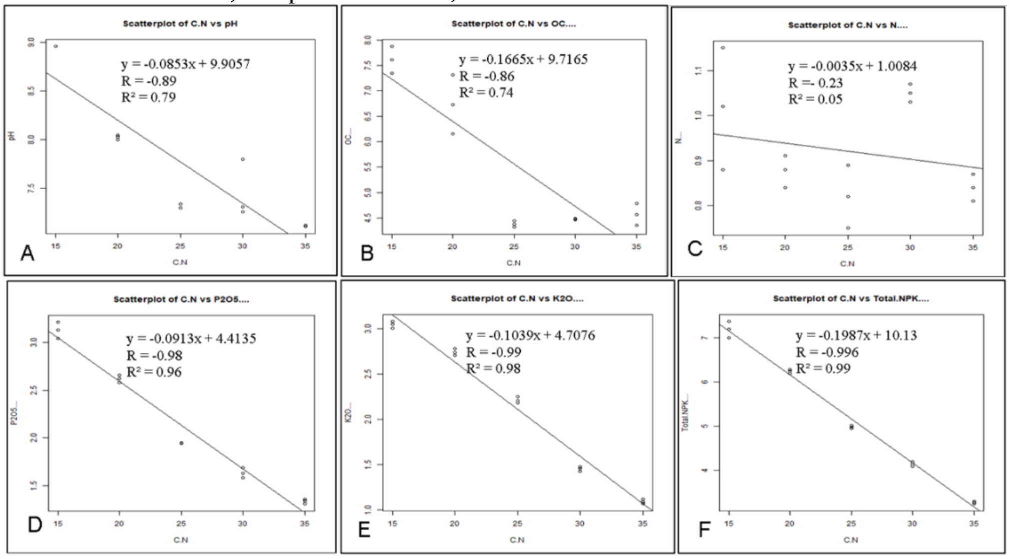

Fig. 4. Scatter plot (correlation) matrix of C/N vs. (A) pH; (B) OC; (C) total N; (D) total P; (E) total K; (F) total NPK of PMR.

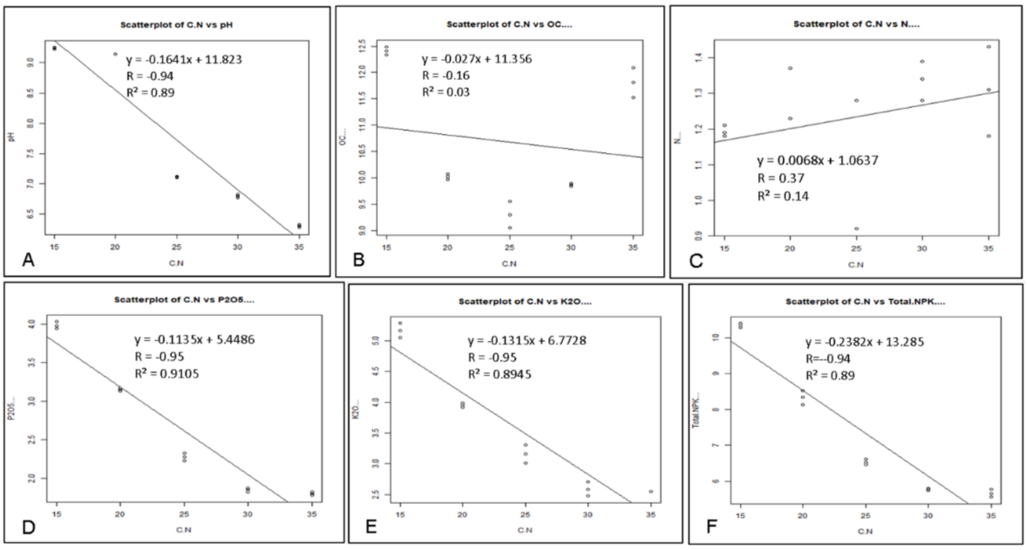

Fig. 5. Scatter plot (correlation) matrix of C/N vs. (A) pH; (B) OC; (C) total N; (D) total P; (E) total K; (F) total NPK of PMCRH

4. DISCUSSIONS

4.1. C/N Ratio, Compost Recovery, and Chemical Property Relationships

Several studies support the positive between C/N ratio and percent compost recovery from both biomass mixtures. For example, Leconte et al., (2009) found that piles with C/N ratios closer to the ideal range exhibited higher organic matter conversion and shorter composting times [14]. Similarly, Soe et al. (2022) observed that mixtures with C/N ratios closer to 25:1 resulted in faster composting and higher compost recovery [15]. Finally, Kumar et al. (2020) observed that nitrogen losses were minimized when the C/N ratio was closer to the ideal range, suggesting efficient nitrogen retention and potentially higher final compost quality and yield [16]. These studies provide strong evidence for the positive correlation between C/N ratio and percent compost recovery. By maintaining an optimal C/N ratio and favorable conditions for microbial activity, enhance decomposition, and ultimately achieve greater compost recovery [17].

4.2. Mixing of Organic Feedstocks

The C/N ratio and moisture content are the two components considered in mixing organic feedstocks. The C/N ratio of organic materials should be proportioned to provide a near optimum C/N ratio. Apart from that, materials that are too dry and too wet to decompose should be blended in proper proportions [18]. In this study, feedstock mixing was based on the volume of feedstock to be incorporated, attaining the C/N ranging from 15 to 35. Composting of poultry manure mixed with carbonaceous materials such as rice straw and CRH helps control both moisture and C/N ratio [1]. The feedstock pile is turned every day to allow uniform decomposition of the file. The feedstock's C/N ratio, hemicellulose, cellulose, and lignin components gradually decrease and stabilize in about five weeks. Similarly, in this study, a low-C/N material whose temperature rises to 70°C is mixed with a high-C/N material to absorb moisture from poultry manure that improves porosity.

During composting, the oxygen consumption in the feedstock pile is directly proportional to microbial activity, which means that the greater the oxygen intake, the higher the temperature. A constant oxygen supply is needed to ensure rapid aerobic and thermophilic composting [1]. Generally, there should be at least 30% porosity in aerobic composting. The addition of porous materials such as rice straw and CRH made it possible in this current study. Furthermore, a daily turning of the feedstock helps decrease the effect of bulking as the feedstock decomposes. The bulk density increases during the process due to a decrease in feedstock volume as it continues to break down and particles become finer [19]

4.3. Factors Affecting Compost Recovery

The PMCRH had greater recovery compared to PMRS (Figure 3). The stability of C in a material added affects the decomposition rate even with similar volumes and C/N ratios in the current study. In the current study, the combination of PMRS and PMCRH retained most of the biomass while preserving the essential macro-elements. Besides the feedstock, several factors affect the decomposition rate, such as aeration, temperature, moisture, pH, particle size, and C/N ratio. All these factors were controlled and made homogenous in the piles except for the C/N ratio. All the piles were turned every day, allowing oxygen to enter the mass. If the piles are poorly aerated, O2 is depleted, leading to CO_2 accumulation that affects the aerobic rate of aerobic composting [1]. Proper aeration is required to control the environment, essential for biological reactions and optimum efficiency [17]. A spike of temperature was observed during the first week of the decomposition and decreased after that until it attained stability after a month. During composting, the microorganisms consume O2, while CO_2 and heat are released [17]. High temperature accelerates decomposition and kills pathogenic organisms. However, prolonged extreme heat retards the decomposition of organic materials. The differences in temperature recorded from the different treatments are due to the changes in the biochemical activities of microbes as affected by the type of feedstock materials with different C/N ratios in the piles (Peters et al. 2000). Karanja et al. (2019) observed a similar range of temperature readings in their experiment on poultry manure and rice straw ranging from 23-56 °C. However, Mortier et al. [17] state that the ideal temperature of the decomposing biomass is 32-60 °C to proceed efficiently.

4.4. Chemical Composition

The feedstocks like rice straw and CRH are rich in C. Rice straw consists of lignin, silica, cellulose, and hemicellulose at 10-15, 75, 40-50, and 9-12%, on a dry basis, respectively according to Knauf & Moniruzzaman [21]. Organic carbon decreases with time due to the degradation of OC. The % OC decrease ranges from 33-44% [19]. In the recent experiment, a decrease of OC was also observed in PMRS ranging from 11-19% and PMCRH ranging from 18-24%. The total N, total P, and total K increased with time due to the release of macro-elements during decomposition in the recent study. The total NPK from all treatments of PMCRH had greater than 5.0 total NPK, unlike PMRS, which means all its products can be considered as organic fertilizers based on the Philippine National Standards for Organic Soil Amendment (PNS-OSA) [22]. The PNS-OSA includes all the products within the scope of PNS, such as organic fertilizers, compost, soil conditioner, and other organic plant supplements. It defined organic fertilizer as any product in solid or liquid form, of a plant (except byproducts from petroleum industries) or animal origin, that has undergone substantial decomposition that a supply available nutrient to plants with a total N, P, ad K of five to ten percent (5-10%). This may be enriched by microbial inoculants and naturally occurring minerals, but no chemical or inorganic fertilizer material has been incorporated into the finished product to alter the nutrient content [22-23]. The total NPK of treatments from PMRS with C/N 15:1-25:1 was in conformity with the standards of OSA as organic fertilizers, while the total NPK of the treatments with C/N 30:1-35:1 can only be categorized as a soil conditioner as they have only total NPK ranging from 2 to < 5.

The conversion of ammonia to nitrate during nitrification increased the nitrate accumulation. This increase led to the decline of the C/N ratio with time in the decomposition period due to losses of organic carbon and CO_2 before it attained stability. El-Haggar [19] observed that the final C/N of the compost could range from 10.5:1 to 14.2:1. However, in the current study, the final C/N ranged from 4:1 to 10:1.

5. CONCLUSIONS AND RECOMENDATIONS

This study investigated the impact of varying C/N ratios on the chemical properties and recovery rates of compost from two feedstock mixtures (PMRS and PMCRH). While increasing the C/N ratio led to higher compost recovery rates, it also decreased some desirable chemical properties like pH, OC, total P, total K, and total NPK. To optimize compost quality and recovery rates, we recommend determining the initial C/N ratios of your feedstocks before mixing. This can be achieved through readily available laboratory analysis or by referring to established C/N ratio ranges for common organic materials. Once you have the individual C/N ratios, you can then calculate the ideal blend ratio to achieve a target C/N ratio for your compost pile. For even faster decomposition, consider co-composting feedstocks with high and low C/N ratios. By strategically mixing these materials, you can create a pile with an initial C/N ratio closer to the optimal range (around 15:1 to 35:1). This approach can potentially accelerate the composting process while maintaining desirable final product characteristics.

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